

and

$$\hat{\sigma}_k = 5.7.$$

Proceeding similarly with the data of the remaining subjects, one obtains estimates of σ_k^2 equal to zero for four of the eight cases; in only one case does $\hat{\sigma}_k$ prove greater than half the value of \hat{d} . For the whole sample, the average of the σ_k estimates is less than 2 elements, whereas the average of the d estimates is approximately 7. No sweeping conclusions should be drawn from this result, since the assignments of pairs of redundant critical elements to positions in the display matrices were not entirely random. (The four corner positions were not used and one member of each pair of redundant elements was required to be on an edge of the matrix; these restrictions are eliminated in a study now in progress.) However, it seems likely, in the light of these preliminary data, that the assumption of a geometric distribution of perceptual spans embodied in a serial processing model for visual detection² will have to be modified.

Finally, it might be noted that the technique presented here offers possibilities of comparing perceptual spans for human and infrahuman subjects. It is well known that many animals, notably pigeons and monkeys, can be trained to attend to a viewing screen upon presentation of a signal and can learn discriminations involving symbols such as those used as critical elements in experiments on visual detection. By training animals to discriminate between displays including varying numbers of redundant critical elements per display, one can estimate statistics of the distribution of perceptual span, and thus in turn evaluate hypotheses as to how subjects of different species process information from visual displays.

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CROSS-MODALITY MATCHING OF BRIGHTNESS AND LOUDNESS*

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In several experiments, observers have undertaken to match for apparent intensity the sensations aroused in two different sense modalities.¹ Despite the uncertainty sometimes expressed about what constitutes equal apparent magnitude in the face of a qualitative disparity (like the well-known difficulty of heterochromatic photometry), the method of cross-modality matching has demonstrated that subjective magnitude grows as a power function of stimulus intensity. The present study undertakes a cross-modality comparison of brightness and loudness—probably the two most important continua having to do with sensory intensity.

The form of the equal-sensation function obtained from a series of cross-modality matches can be tested against the predictions of the psychophysical law proposed by S. S. Stevens, which states that the subjective magnitude ψ grows as a power function of the stimulus magnitude ϕ . For two continua that obey the power law, the psychophysical equations can be written as follows, omitting constants that depend on units:

$$\psi_a = \phi_a^\alpha \quad \text{and} \quad \psi_b = \phi_b^\beta. \quad (1)$$

Empirical functions of this kind can be obtained by means of numerical assessments of sensory magnitude by such scaling methods as magnitude estimation. The stimulus levels that produce matching values between ψ_a and ψ_b generate the function

$$\phi_a^\alpha = \phi_b^\beta, \quad (2)$$

which can be written

$$\log \phi_a = \beta/\alpha \log \phi_b. \quad (3)$$

Equation (3) shows that in log-log coordinates the equal-sensation function becomes a straight line with the slope given by the ratio β/α of the two original exponents.²

The present study used the method of cross-modality matching in order to determine whether brightness and loudness would produce an equal-sensation function whose exponent is the ratio of the exponents previously determined for these two sense modalities.

Method.—Ten observers took part in each of two experiments. Four of the ten served in both experiments. Each experiment had two sessions separated by at least a day. Before every session the eyes were dark-adapted with red goggles for 10 min. All sessions were conducted in a dark room.

In experiment 1 a band of noise, 75–4800 cps, was presented binaurally through PDR-8 earphones. Its onset was simultaneous with the onset of a luminous target of white light subtending 4° and placed 63 cm in front of the right eye. A red fixation spot, centered on the target, was turned off when the target came on. The duration of each burst of noise was 0.95 sec, that of the light 0.45 sec, and that of the interval between the offset of the noise and the next onset of the noise and light 8.5 sec.

In the first session of experiment 1, five observers were presented with eight luminance levels between 50 and 100 db re 10^{-10} L. These levels were presented twice each in irregular order. The observer rotated the knob of a "sone potentiometer"³ that permitted a 100-db variation in the level of the noise, and he was instructed to arrive at a loudness setting that seemed to match subjectively the brightness of the light. The light and sound cycled on and off until the observer signaled that he had made his setting.

In the second session of experiment 1, the same five observers varied the light to match the sound by adjusting a knob that rotated a pair of 40-db neutral density wedges mounted on a common shaft, an arrangement that permitted a continuous variation in luminance of almost 80 db, or 8 log units. Eight levels of the sound, between 45 and 95 db re 0.0002 dyne/cm², were presented twice each in irregular order.

The other five observers of experiment 1 made the same judgments, but in reverse order; first they adjusted the light and later the sound.

The wait of more than 8 sec between stimuli placed a strain on both memory and patience. Hence, in experiment 2 the observer was allowed to control the onset and offset of both stimuli by pressing a pair of keys. The sound and light could be experienced simultaneously or successively, at the observer's pleasure. He was asked, however, not to view the light continuously for

long durations and, if afterimages occurred, to wait for them to dissipate. Seven stimulus levels were matched in each session.

Although the observer was not aware of it, the first judgment of each session in both experiments was for practice, and the result was not used in the analysis of the data.

Results.—The average decibel settings are plotted in Figure 1 (expt. 1) and Figure 2 (expt. 2). The four equal-sensation functions approximate linear functions in the decibel (or log-log) coordinates and therefore conform approximately to equation (3). When the sound was adjusted, a steeper slope resulted than when the light was adjusted. In other words, the observer tended to shorten the range of whichever stimulus he adjusted, as happens regularly in both cross-modality matching and other psychophysical procedures.⁴ In a balanced experiment, it is presumably possible to average out some of the effects of the observer's tendency to shorten the range of the variable he controls. The average slope, for both experiment 1 and experiment 2, turned out to be about 1.0, but the adjustment of either variable by itself would have yielded a higher (about 1.1) or lower (about 0.9) estimate of the slope.

A slope of 1.0 is close to the value predicted from the two psychophysical functions governing brightness and loudness. The exponent of the brightness function has been shown repeatedly to be about 0.33.⁵ For the loudness of a band of noise the exponent is also in the vicinity of 0.33, when expressed in terms of sound energy, or 0.66 in terms of sound pressure. (Energy is proportional to the square of the pressure.) The exponent for noise appears to be a little larger than the exponent (0.3) of the sone function for the loudness of a 1000-cycle tone.⁶ The derivation of equation (3) shows that the ratio of the exponents governing loudness and brightness should, in fact, approximate unity.

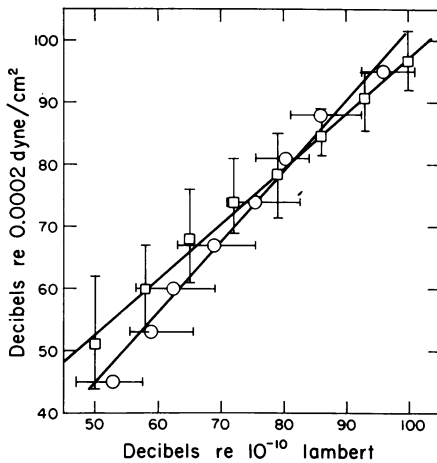


FIG. 1.—Equal-sensation functions for loudness and brightness, showing the levels of luminance and sound pressure that appeared equal in subjective intensity (expt. 1). *Squares*: sound adjusted to match light; *circles*: light adjusted to match sound. The vertical and horizontal line segments show the interquartile ranges of the adjustments. These ranges become much smaller when the intercept variability is removed.

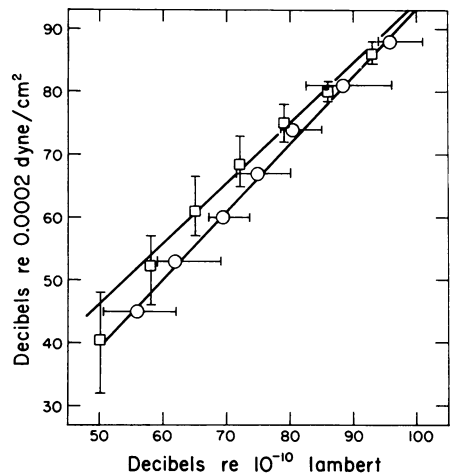


FIG. 2.—Equal-sensation functions for loudness and brightness, showing the levels of luminance and sound pressure that appeared equal in subjective intensity (expt. 2). *Squares*: sound adjusted to match light; *circles*: light adjusted to match sound. The vertical and horizontal line segments show the interquartile ranges of the adjustments. These ranges become much smaller when the intercept variability is removed.

TABLE 1
AVERAGES OF THE INTERQUARTILE RANGES IN DECIBELS BEFORE
AND AFTER REMOVAL OF THE INTERCEPT VARIABILITY

	Interquartile Ranges	
	Before	After
Expt. 1		
Light adjusted	8.1	6.0
Sound adjusted	12.7	7.5
Expt. 2		
Light adjusted	9.5	5.2
Sound adjusted	8.2	5.4

The interquartile ranges, plotted in Figures 1 and 2, show the variability of the settings. These ranges do not signify random variation alone, however, for although observers may differ from one another on what constitutes a match in the absolute sense, they may still agree quite closely about relative magnitude. In fact, it is possible to partial out the variability that stems from differences in the absolute sense, that is to say, the intercept variability due to the average absolute levels selected by the different observers. The procedure is as follows.⁷ First, the grand mean of all the settings of the group and the means of all the settings for each individual are calculated. Then, for each observer, the difference between the grand mean and the individual mean is calculated and added to all his settings. This procedure leaves unchanged the group means that are plotted in Figures 1 and 2, but, as can be seen from Table 1, the average interquartile range of the settings treated to remove the intercept variability is about 65 per cent as large as that of the untreated settings. The intercept differences are shown thereby to contribute a substantial portion of the variability encountered in these cross-modality matches.

Although the slopes for experiment 1 are nearly the same as those for experiment 2, the intercepts of the equal-sensation functions seem to have been influenced by the procedure. When the observer was permitted to view the light at will (expt. 2), he selected on the average a higher luminance to match a given sound pressure. The higher level of light adaptation caused by repeated viewing may account for the intercept difference, because moderate light-adaptation can cause a substantial depression of brightness with only a small effect on the exponent of the brightness function.⁸ Despite the small difference in intercepts, the two experiments concur in demonstrating that the power law relating subjective magnitude to physical intensity can be corroborated by nonnumerical assessments of subjective magnitude, and that brightness and loudness are similar functions of stimulus energy.

Summary.—Observers matched the brightness of a light to the loudness of a noise, and vice versa, at various levels of intensity. The cross-modality functions thereby generated have the form predicted by the psychophysical power law of sensory magnitude, and they demonstrate that the psychophysical functions relating brightness and loudness to the level of stimulus energy have approximately the same exponents.

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JUVENILE HORMONE ACTIVITY FOR THE BUG *PYRRHOCORIS APTERUS**

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When transported from Prague to Boston and reared in the Biological Laboratories at Harvard University, the bug *Pyrrhocoris apterus* failed to undergo normal metamorphosis. Approximately 1500 individuals were reared from eggs. Instead of metamorphosing into normal adults, at the end of the 5th larval instar all molted into 6th instar larvae or into adultoid forms preserving many larval characters. Indeed, as illustrated in Figure 1, some continued to grow and molted into still-larger 7th instar larvae. Without exception, all individuals died without completing metamorphosis or attaining sexual maturity.

During 10 years of culturing *Pyrrhocoris* in Prague, not a single instance of this sort had been observed. Additional larval instars, in *Pyrrhocoris* as in other species, had been induced only by the implantation of active corpora allata (the endocrine source of juvenile hormone), or by the injection or topical application of substances showing juvenile hormone activity.¹ Evidently, when reared at Harvard University, the bugs had access to some unknown source of juvenile hormone.

An audit of the culture conditions at Harvard versus Prague suggested 15 differences. By systematic study, 14 were eliminated. The source of juvenile hormone activity was finally tracked down to exposure of the bugs to a certain paper towel